CONF-801011--2

LA-UR 80-2941

MASTER

TITLE: PRESENT STATUS AND FUTURE DEVELOPMENT OF WNR

AUTHOR(S): G. A. Keyworth

SUBMITTED TO: ICANS-IV
KEK, Tsukuba, Japan
October 20 to 24, 1980

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87545

DEPARTMENT OF ENERGY
CONTRACT W-7405-ENG. 36

I. INTRODUCTION

The Los Alamos Weapons Neutron Research/Proton Storage Ring complex (WNR/PSR) will be a major United States facility for the study of condensed matter science, fundamental interaction physics, and nuclear physics. It will serve as a major adjunct to the Los Alamos Meson Physics Facility (LAMPF) and will contribute to its role as a thriving research center.

Our objective in developing the WNR/PSR is to provide a facility and to support the development of research programs of the highest possible quality in several areas of fundamental science of particular current interest. We believe strongly that the existence of a multidisciplinary scientific program at the WNR/PSR will produce many synergistic interactions between the contributing disciplines that will make the facility exciting and productive.

Current interest in substantiating our theoretical understanding of the nature and role of the weak interaction provokes intense interest in the use of thermal and ultra-cold neutrons both for studying the intrinsic properties of the neutron itself, such as the electric dipole moment, and in the role of the weak interaction in neutron-induced nuclear reactions. The unique properties, including the non-critical nature, of pulsed spallation sources are particularly well suited to the production of intense beams of slow neutrons with minimum background for these studies.

Pulsed spallation sources have another application of intense current interest that is often not fully recognized. During the early stages of development of the WNR research program, it became evident that the future Proton Storage Ring would have a major impact on our ability to do neutrino physics at LAMPF. In experiments where the signal-to-noise ratio is primarily determined by the cosmic ray background, pulse compression has an obvious and direct advantage. Although the neutrino energy spectrum available with LAMPF protons is low compared to other major neutrino producing facilities, the neutrino intensity is unparalleled. In addition, current interest in studying the intrinsic properties of the neutrino, such as the existence of neutrino "oscillations", lend a renewed interest to relatively low-energy neutrino sources. This capability of the WNR/PSR will represent a major element of our multidisciplinary scientific program.

There has been no major new pulsed neutron source constructed in the United States in more than 12 years. A great variety of nuclear physics and nuclear structure questions have arisen that cannot be addressed by existing sources, such as the Oak Ridge Electron Linear Accelerator. The WNR/PSR will provide a source of neutrons from thermal energies to several hundred MeV with an intensity more than an order of magnitude greater than is currently available with existing sources. Thus, the WNR/PSR represents a major element in the future of our Laboratory's traditional emphasis upon nuclear physics.

In the last 20 years, neutron scattering has amply proven itself as a uniquely powerful tool for studying many of the properties of condensed matter. Although the United States continues to maintain a prominent position in neutron scattering research, superior facilities and support in Europe and elsewhere are rapidly eroding this position. We believe that through the development of the WNR/PSR facility and its attendant research programs the United States will continue to maintain a position at the forefront of neutron scattering research. The WNR/PSR will permit both assessment of the opportunities offered by pulsed spallation sources for neutron scattering as well as achievement of the major requirements specified for the next generation of advanced neutron sources.

A neutron scattering program was initiated at the WNR facility in 1978. The major direction of our program to date has been to explore the performance characteristics of a pulsed spallation source, to develop instruments, and to perform those significant experiments possible with a relatively low ($< 10^{14}$ n/cm^2-s) intensities. The PSR will be completed by 1985 and will increase the peak thermal flux available at the WNR by two orders of magnitude. At that stage, the United States will possess a pulsed neutron facility with a peak thermal flux significantly greater than the steady-state flux from any research reactor in the world, as well as a completely new regime of epithermal neutron intensity.

The WNR/PSR will be open to both the United States and international scientific communities. LASL has a long history of university contacts and is operated by the University of California under a government contract. The international users program at the present LAMPF facility comprises more than 1000 members.

II. FACILITIES

The LAMPF 800-MeV linac is the world's highest intensity (1 mA) proton accelerator. The already operational WNR facility can only accept less than 1% (< 10 μA) of the LAMPF beam without having undesirably long pulse lengths for time-of-flight techniques. The PSR will compress the LAMPF pulse as well as provide variability in repetition rate, thus enhancing the overall power and versatility of the WNR by 2-3 orders of magnitude for condensed matter research and even more for some other applications such as nuclear and neutrino physics. With relatively minor upgrading of the present WNR target, the WNR/PSR will by 1986 be able to accommodate an average proton current of 100 μA and thus achieve a peak thermal neutron flux of 1.2×10^{16} n/cm^2-s with pulse characteristics optimally matched to experimental time-of-flight requirements for neutrons ranging over ten decades (0.01 eV - 100 MeV) of energy.

A. <u>The Los Alamos Meson Physics Facility</u>

LAMPF consists of a three-stage, high-intensity linear accelerator designed to provide a beam of protons at variable energies up to 800 MeV with an average current of 1 mA. The facility is also designed to permit simultaneous acceleration of beams of H^- ions, that will be required for input to the PSR. The LAMPF pulse profile is characterized by a macrostructure of 120 pulses per second, each approximately 750-μs long for the presently utilized 9% duty factor. Each macropulse in turn has microstructure consisting of a 50-100-ps burst every 5 ns.

The present LAMPF proton current of approximately 600 μA is constrained by target and experimental area considerations, rather than by accelerator capacity. Tests at higher currents have already indicated that the LAMPF accelerator can readily produce more than 1 mA. As with most other major research accelerators in the United States today, budget restrictions limit LAMPF to approximately six months of production per year.

A number of modifications to the LAMPF accelerator are however necessary to permit injection of 100 μA of H^- ions into the PSR. Studies by LAMPF personnel indicate that the necessary modifications can be designed and executed with only minor impact on the present operating features and production schedules. The incremental operating costs for LAMPF to supply 100 μA of H^- to the PSR are estimated to be about 3.5% of the annual LAMPF operating budget.

B. Proton Storage Ring

The function of the PSR is to accumulate relatively long proton pulses from LAMPF and to restructure them into sequences of narrow, intense pulses optimized for the time-of-flight techniques utilized at the WNR. For many nuclear physics applications, pulse widths of approximately 1 ns and high repetition rates are needed for optimum energy resolution and count rates. However, for applications where thermal and epithermal neutrons are required, pulse widths can be several hundred ns but the repetition rate must be low (10-50 Hz) to avoid frame overlap. The PSR is designed to operate in two different modes that separately optimize pulse performance for the high- and low-energy applications. In the high-energy mode, the PSR will accumulate protons in six equally spaced 1-ns long bunches to deliver protons to the target at a 720-Hz repetition rate with an average current of 10 μA. In the low-energy mode, the PSR accumulates protons in a single 270-ns pulse, and ejection is at 12 Hz. Although the presently designed average current level is 100 μA, raising the repetition rate permits a proportional increase in the average current, ultimately permitting delivery of currents significantly greater than 100 μA to an appropriate target facility.

C. Weapons Neutron Research Facility

The WNR facility was designed and built to accept up to 2% (20 μA) of the LAMPF beam. The protons impinge upon a high-Z target producing, through spallation reactions, a polychromatic spectrum of neutrons extending from 800 MeV down to approximately 100 keV. Hydrogeneous moderators adjacent to the target effectively reduce this neutron energy spectrum for low-energy applications. In addition, there is a second, low-current target room which can accommodate proton beams up to 0.1 μA.

The proton beam enters into a service cell in the high-current target where it impinges upon a high-Z target. The service cell permits access to the target in the crypt below. The crypt holds two target assemblies, and four large moderator assemblies which are mounted on remotely controlled mechanisms allowing a variety of target-moderator configurations tailored to the needs of various experimental programs. A 3.8-m-thick target shield surrounds the crypt and limits dose rates to less than 1 mrem/h at its outer surface with 10 μA of 800-MeV protons on target. This shield is penetrated by 12 neutron flight paths. Each penetration consists of a graduated opening that can be filled with collimators and beam shutters as required. Some of these flight paths can be extended outside the experimental room (beyond 15 m) with flight path 1 presently developed to 200 m. The WNR was designed to permit personnel access to the main experimental floor at all times. In order to operate the WNR at the 100-μA level some modest upgrading of the target cell and shield is required.

The long-pulse, low-repetition-rate mode of operation of the PSR can simultaneously accommodate all projected applications except those nuclear physics measurements requiring high-energy neutrons and high resolution. Present and projected scientific emphases indicate that such fundamental interaction measurements as the electric dipole moment of the neutron and determination of the parity-violating component in the n-p system as well as neutrino physics will receive major interest. If an additional, high-current target area is built, then the enormous potential for neutrino physics achieved by the compression of the LAMPF pulse by > 10^4 can be realized in simultaneous and noninterfering operation with the condensed matter science program. With these considerations, we project that the operating mode will be optimum for the needs of the condensed matter science community at least 80% of the production time. Mechanisms are currently being studied to further increase this fraction through multiplexing techniques. Of course, this projected fraction may be modified by outstanding requirements of particular experiments as evaluated by members of the user community and LASL staff. Such questions surpass disciplinary boundaries in import.

III. RESEARCH

The particular attraction of the WNR/PSR rests in those performance characteristics which open up completely new areas of science. In the following we shall briefly describe the present status of our research efforts and indicate some future directions that appear to be particularly exciting.

A. Weak Interactions

A number of fundamental tests of the role of the weak interaction in nuclear reactions and in nuclear decays remain essential to establishing the validity of current weak-interaction theories. The extremely high peak intensities of neutrons and neutrinos available at the WNR/PSR facility will provide a unique opportunity to explore this fundamental area of research.

It is already possible to conduct some measurements with neutrinos at LAMPF. The PSR, however, will enhance the peak intensity available by nearly a factor of 10^5. There already exists intense interests in the nuclear and particle physics communities to use the PSR for these measurements.

Neutrons themselves also represent a powerful tool by which to measure the weak-interaction component in strong interactions. However, this weak-interaction component is generally a miniscule fraction of the total interaction. Thus, intense beams of very low-energy neutrons are required to provide adequate statistics and high cross sections. We are currently exploring the feasibility, with encouraging results, of using the WNR beam to explore the parity-violating, weak-interaction component in the fundamental interaction between neutrons and protons by measuring the circular polarization of the gamma-rays resulting from n-p capture.

Another fundamental measurement is the magnitude of the electric dipole moment of the neutron as a measurement of the weak interaction component in this fundamental decay. We are currently collaborating with university researchers to develop techniques to exploit the WNR facility as a source of ultracold neutrons to support this and other measurements.

B. Nuclear Physics

Because of the difficulty in producing and detecting neutrons, the study of nuclear structure using neutrons as a probe is a difficult art. With the advent of the PSR at the WNR facility, sufficient intensity will become available to substantially reduce this inherent difficulty and will permit unprecedentedly high energy resolution.

One of the major experimental tools currently under development at LASL involves using beams of polarized neutrons and polarized targets to explore the role of spin in nuclear reactions through the study of nuclear resonances. We expect this technique to reveal new vistas in our understanding of nuclear structure, as preliminary experiments using polarized neutrons on polarized fissionable nuclei have already revealed.

The PSR will permit us to produce high intensity pulses of high energy neutrons of 1-ns duration to allow measurements with very high energy resolution. For example, as theoretical understanding of quark-gluon models of fundamental nuclear structure evolves, evidence of this radically new picture of nuclear matter may conceivably display itself in aspects of nuclear structure. The unique capability for high-resolution experiments with neutrons at the WNR/PSR will offer a high-precision tool for exploring such microscopic phenomena in nuclear reactions.

C. Condensed Matter Science

1. Motivation

The development of the WNR/PSR pulsed neutron source at Los Alamos and the new synchrotron light sources provide the next generation of facilities required for the United States to remain at the forefront of condensed matter science in the next decade. The WNR/PSR is the only next generation United States thermal neutron source under construction capable of providing an order of magnitude improvement in peak flux over the highly successful, but aging, research reactors at BNL and ORNL. It will permit us to remain competitive in the 1980's with new pulsed neutron sources at various stages of development throughout the world.

The WNR/PSR will provide access to new areas of scientific research. For example, neutron scattering at epithermal energies ($E > 0.1$ eV) will be practical for the first time because of the several orders of magnitude increase in epithermal flux compared to research reactors ($\phi \sim 1/E$ for WNR/PSR whereas $\phi \sim e^{-E/kT}$ for reactors). The potential applications for using the large energy and momentum transfer possible with epithermal neutrons are vast, ranging from chemical spectroscopy to crystal field levels of magnetic rare-earth atoms.

It should be noted that the WNR/PSR can provide information complementary to that provided by investigations at synchrotron light sources. It will be possible to probe electronic transitions in the characteristic eV range of magnetic materials by coupling to the neutron magnetic moment while synchrotron light permits measurements of electronic band structures in the same range through photoelectron spectroscopy. In general, the new synchrotron light sources and the WNR/PSR will extend the complementary aspects of neutron and x-ray sources into new energy and intensity ranges.

The WNR/PSR will also be complementary to research reactors. For example, hydrogen potentials in metal hydrides as determined through inelastic epithermal neutron scattering are important to understanding hydrogen diffusion as inferred through measurement of quasielastic scattering at reactors.

The pulsed nature of the WNR/PSR source and time-of-flight instrumentation will also offer substantial advantages for many measurements. Examples are powder, amorphous, and liquids diffraction where there is an increase of two orders of magnitude in the number of useful resolution elements over that possible with steady-state experiments.

2. Development of the Neutron Scattering Program

Because of the obvious scientific potential of the WNR source, LASL initiated a new neutron scattering research group in 1978. The present mission and expected development of this group is coupled to the planned improvements in neutron source performance and to a growing role in serving a national user community.

With the neutron source characteristics expected between 1980 and 1985, 11 μA of 800-MeV protons in 8-μs pulses at frequencies up to 120 Hz, the WNR will be a factor of 50-100 more intense than the old Harwell linac upon which is based much of the confidence in the scientific future of pulsed neutron sources. An initial objective during this period will be to develop and test new instrument concepts required for optimal utilization of both the WNR and the much more intense WNR/PSR. This development is required due to limited experience with time-of-flight instrumentation at existing reactors and electron linacs, the unprecedented source characteristics such as the fast neutron background, and advances in technology in areas such as data acquisition and position sensitive detectors that make practical envisioning experiments with millions of resolution elements. As successful instruments are built they will be used to explore those scientific questions to which they are suited.

The changes in neutron source characteristics after PSR operation commences in 1985 will make the WNR a much more versatile and powerful tool for condensed matter research. As discussed above, the WNR/PSR will provide 100 μA of 800-MeV protons to a target in 0.27-μs pulses resulting in a 1.2×10^{16} n/cm^2-s peak thermal flux at a repetition rate of 12 Hz. This capability will also permit an order of magnitude improvement in time-of-flight resolution and in flux for experiments with epithermal neutrons. For example, liquids diffraction studies without the uncertainties of Placzek corrections should be possible. With a peak thermal flux of 10^{16} n/cm^2-s the source will also be competitive with research reactors for most applications in the thermal neutron range. For example, the high intensities will make possible studies of small volumes of difficult to obtain samples or of difficult to observe phenomena. The low repetition rate and easy implementation of cold moderators will be especially advantageous for experiments with long-wavelength neutrons. Thus, the WNR/PSR will be competitive for polymer studies by small Q scattering, diffusion studies in solids by quasielastic scattering, and surface studies by ultracold neutrons.

At this point, it is easy to continue to speculate on the specific areas of science upon which the WNR/PSR will have the most dramatic impact. However, the history of such predictions shows that much of the best science that will ultimately develop at the WNR/PSR will elude our best prediction. The important considerations are that neutrons are a proven powerful probe of condensed matter, and that the WNR/PSR will provide neutrons at new intensities, energies, and with a time structure that will permit development of new experimental techniques.

Experience with the WNR/PSR will make possible an assessment of the value of yet another regime of neutron intensity potentially available with spallation sources. The WNR/PSR itself will still have considerable capacity for further flux increases because of the 1 mA and greater intrinsic capability of LAMPF.

3. Present Activities in Neutron Scattering

The immediate activities of the neutron scattering program at LASL include a number of experiments that benefit from the unique characteristics of the WNR, support the development of a set of prototype time-of-flight instruments, or support the development of the WNR as a facility. The WNR is now close to being in a production mode for condensed matter research.

The initial inelastic neutron scattering research program has emphasized the study of local phonon modes in solids, and chemical spectroscopy. The most productive research area has been the measurement of the high-energy vibrational spectra of metal hydrides. This information is used to determine hydrogen potentials, hydrogen sites, anharmonicity, and the effects of phase transitions. These potentials are of particular importance in understanding the probable quantum mechanical origin of fast hydrogen diffusion in these materials.

Preliminary measurements have also been conducted of the spectra of hydrocarbons absorbed on surfaces. These observations should make it possible to monitor the evolution of chemical reactions and to determine bonding sites at surfaces. These results will complement measurements at lower energy transfer performed at reactors. The particular approach we have pursued is to use large surface area materials such as grafoil and dispersed-metal catalysts. Also, we have examined the vibrational spectra of metallic hexamines where severe distortions of NH_3 groups have been indicated. Such measurements are carried out using a crystal analyzer spectrometer which is particularly suited to measurements at large energy ($\Delta E > 0.1$ eV) and large momentum transfers ($\Delta Q > 2$ A^{-1}).

For future development, we are evaluating concepts such as constant Q and high symmetry spectrometers. These instruments would permit studies of elementary excitations in single crystals. A possible application would be the study of very high stiffness spin wave spectra.

The most versatile instrument for inelastic scattering measurements at pulsed sources will probably be a neutron chopper. We have been experimenting with a 240-Hz chopper with Cd slits acquired from the now defunct MTR reactor. We have accomplished phasing the chopper to the neutron pulses by controlling both the chopper frequency and phase by active damping, and by controlling the firing of LAMPF proton pulses. The chopper has been used to confirm observations made with the crystal analyzer of a 15-MeV splitting of the hydrogen fundamental in TiH_2. The The next step is to develop a chopper suitable for high energy transfers ($\Delta E > 0.2$ eV), to construct proper shielding and collimation, and to build a detector bank suited to both large Q scattering, such as required for measurement of the Bose condensate fraction in He II, and very low Q scattering, such as required to minimize recoil broadening in molecular and solid state spectroscopy.

Time-of-flight methods have particular advantages in structural studies of materials in extreme environments. The detector bank can subtend a small solid angle with a restricted view of the sample, and still satisfy the Bragg condition by varying the wavelength. Such a special environment diffractometer is in routine use for the study of the equation of state of Pu at pressures up to 5 kbar and temperatures up to 350° C. We have measured variation of the lattice constant with pressure within the δ phase and have observed large hysteresis effects. The detector bank is "geometrically time focused" so that neutrons of a given energy arrive at all detectors at the same time. The resolution achieved is $\Delta d/d \sim 0.7\%$. With improvements to the instrument currently being implemented, only one hour of beam time will be required to obtain a good pattern.

Another versatile instrument is a general purpose diffractometer which is under development for structural studies of powder, liquid, and amorphous materials. Using detectors at angles between 10° and 150° it is possible to cover the small-Q range important for minimizing Placzek corrections in liquids diffraction as well as the large-Q range important to high resolution powder diffraction and molecular liquids diffraction. This instrument will be electronically time focused. Counts will be recorded for individual detectors and differences in flight times will be compensated for by computer. The electronic time focusing makes it possible to use large solid angles with greatly increased count rates compared to those achievable with a geometrically focused instrument. Another concept that will be tested is "geometric resolution focusing". This technique decreases the solid angle slightly, but allows all detectors within a bank to have the same resolution so that their outputs may be simply combined. For high resolution powder studies, the instrument should attain $\Delta d/d \sim 0.5\%$ and be capable of measuring smaller d-spacings than comparable reactor instruments. This measurement is useful, for example, in determination of parameters of several coexisting phases in a sample where the Bragg peaks are close together. The count rate is expected to be better than the best powder instrument at the ILL and the resolution will be comparable.

The initial experiments in molecular liquids diffraction will explore determination of the hydrogen-hydrogen correlation function in water. This will employ an isotope substitution method to remove first-order Placzek corrections without requiring introduction of models of the inelastic spectra. When combined with the WNR capability to determine the scattering function at very large Q, the experiments will provide a model-free test of theories of water structure.

A single crystal diffractometer based on the Laue time-of-flight method is being developed. This instrument uses a position-sensitive area detector to simultaneously measure many Bragg peaks, as well as to determine the incoherent and diffuse background. The single crystal diffractometer is an example of an instrument made possible by advances in data acquisition. It uses a high speed megaword memory being developed by LASL in collaboration with ORNL. Our initial experiments will involve the determination of hydrogen positions in organometallic catalysts. Another obvious application is to the study of order-disorder transitions in solids. Because of the capability to measure high-index reflections using the high epithermal flux, one can also determine the thermal parameters and lattice anharmonicity in the A-15 superconductors.

The source characteristics of the present WNR are adequate for many moderate resolution experiments. None of the existing instruments suffer significant loss in time-of-flight resolution at 8-μs pulse widths and they do not require long-wavelength neutrons which would produce frame overlap. Further experiments, extending into the epithermal range, may require a lengthening of the flight path or a reduction of the pulse width to achieve adequate resolution, at some sacrifice in intensity. Experiments at longer wavelengths may require either pulse choppers or velocity selectors to avoid frame overlap.

The advent of the PSR will provide pulse widths and repetition rates where time of-flight resolution is limited only by the moderators and where frame overlap is negligible. It will also make chopper phasing easy by allowing WNR choppers to time the extraction of beam from the PSR

Future activities in the neutron scattering program will aim toward building special capabilities for exploiting the unique characteristics of the WNR pulsed neutron source. This may include developing neutron polarizers, resonance detectors, and pulsed sample environments. Polarized neutrons have applications in the study of magnetic materials, in the isolation of hydrogen behavior in catalytic systems by scattering resulting in spin flip transition, and the inelastic spectroscopy by the spin-echo method. Resonance detectors may be essential to spectroscopy at several eV energy. Pulsed sample environments will permit kinetic studies such as glass crystallization.

Polarized neutrons and resonance detectors are examples of areas where the multi-disciplinary program pursued at the WNR will contribute directly to the development of a condensed matter research effort. Polarized proton targets are routinely used at LAMPF and the WNR to determine spins of nuclear resonances as well as to explore the nucleon-nucleon system at intermediate energies.

IV. POSSIBLE ADVANCED SPALLATION FACILITY

The uniquely high proton current intensity of at least 1 mA produced by LAMPF provides the basis for an even more advanced and intense spallation neutron source.

If the scientific opportunities appear sufficiently promising, LASL will propose to build a new target area to utilize the full potential of the LAMPF accelerator to achieve yet another major increase in neutron source intensity. Such a facility might use 1000 μA of protons from LAMPF delivered to a new target and would produce a peak thermal flux of between 10^{16} and 10^{17} n/cm^2-s depending upon repetition rate.

An advanced pulsed spallation facility of this type would be considered for development after 1990. It is compatible with current plans under study to develop a post-accelerator to LAMPF for kaon and anti-proton physics. Such an accelerator, perhaps a synchrotron of $\geq$ 15-GeV energy, would utilize only 100-μA of the LAMPF current, while dominating the nuclear and particle physics program at LAMPF. Utilizing then the remaining high-current capability intrinsic to LAMPF for a high-current ($\sim$ 1 mA) spallation source would be feasible.

The following would be required to develop this source:

A. LAMPF

LAMPF will have sufficient capacity to provide at least 1 mA of proton current. No additional construction or modification beyond that already implemented or planned for 100-μA operation is expected to be required. The entire scientific opportunities at LAMPF will need to be examined in order to determine the amount of current to be devoted to a spallation neutron source.

B. PSR

The PSR is conservatively designed to accommodate 100-μA average current at 12 Hz. If beam loss is sufficiently low, 400-μA operation could be achieved immediately by operating at 48 Hz. The ultimate capacity of the PSR and the exact nature of any required modifications will only become clear when actual operating experience becomes available. However, we do believe that up to 1-mA operation may be possible with modest modifications.

C. Target Area

The present WNR target area cannot be upgraded in a reasonable manner to accommodate proton currents beyond 100 μA. Thus an entirely new target area would be required for 500-1000-μA operation. It is clear that such a target area would represent the major cost for this spallation source and preliminary studies indicate \$40-50 M might be required. These studies also indicate that this target area could accommodate simultaneous use for condensed matter science and neutrino physics, although the need for two shared, high-current targets is not excluded.